Proximity Effects of Plastic Laptop Covers on Radiation Characteristics of 60-GHz Antennas

Arnaud L. Amadjikpè, *Student Member, IEEE*, Debabani Choudhury, *Senior Member, IEEE*, George E. Ponchak, *Fellow, IEEE*, Bo Pan, *Member, IEEE*, Yuan Li, *Student Member, IEEE*, and John Papapolymerou, *Senior Member, IEEE*

***Abstract*—This letter highlights impacts on radiation characteristics of 60-GHz antennas operated in the proximity of plastic laptop covers. A series of experiments are carried out with antennas placed under plastic laptop cover materials. Antenna peak gain attenuation through the plastic cover materials is characterized as a function of frequency, distance between antenna and cover, as well as dielectric properties of the materials. The attenuation is moderate and in the order of 2 to 4.5 dB. Diffraction occurs at the cover edges and results in nulls in the antenna radiation pattern. The direction of the nulls is aligned with the cover edges. A null corresponds to more than a 15-dB drop in the antenna gain and might result in a link failure for 60-GHz point-to-point communications.**

***Index Terms*—60-GHz antennas, electromagnetic diffraction, laptop material environment, millimeter wave, radiation characteristics.**

I. Introduction

The 60 GHz unlicensed spectrum (57–66 GHz) has received a lot of attention over the last couple of years for enabling short-range and over 1 Gbps high-speed wireless communications. Some potential applications of the 60-GHz technology include fixed wireless access, wireless local area networks (WLANs), wireless personal area networks (WPANs), and portable multimedia streaming [1]. 60-GHz services will be provided using portable devices such as laptop computers, personal digital assistants (PDAs), and DVD players. The protection package of these devices is usually made of a plastic cover material, which constitutes a discontinuity in the propagating air medium. The proximity of the plastic cover with the 60-GHz antenna may alter its free-space performance. The wavelength at 60 GHz is small enough to create strong interference with small obstacles on the covers, and understanding of signal attenuation is critical because very high antenna gain is required at 60 GHz to communicate at the desired distances with high data rates.

Extensive efforts have been made in the design of planar antennas, integrated antennas, and on-chip antennas [2]–[7]. The cited literature mainly focuses on the modeling and design aspects for high-performance, compact, and low-cost 60-GHz antennas in free-space environment. The objective of the work presented in this letter is to go beyond the antenna modeling aspects in free space and identify the proximity effects of plastic material covers on the 60-GHz antenna performance.

The attenuation of an RF signal radiated normal to a plastic laptop cover is presented as a function of frequency, the distance between the laptop cover and the transmitting antenna, as well as the dielectric properties of the cover. The cover is also tilted with respect to the transmitting antenna to evaluate the effects on an oblique incidence of the RF signal onto the cover. Some material characteristics are extracted from the measured data and used to analyze the impact on signal attenuation.

In order to investigate the diffraction effects from different regions of a laptop cover, the attenuation between two standard gain V-band horns is measured by placing a rotating laptop cover in between. A more realistic scenario, involving a laptop-mounted micromachined V-band planar antenna [6], is shown to further demonstrate and support the results observed with the two standard gain horns. The micromachined V-band planar antenna is a substrate-integrated antenna that has demonstrated as high as 14.6-dBi peak gain and can be used as a good testing device for these experiments.

II. Antenna Gain Attenuation and Characterization of Plastic Laptop Cover Materials

This section presents the experimental studies on the 60-GHz signal attenuation through plastic laptop cover materials. Two V-band standard gain horn antennas (TRG 861U/383) are used in a calibrated anechoic chamber to carry out the experiments.

A. Normal Incidence of the Antenna Main Beam to the Plastic Cover

Laptop covers are usually made with plastics that are lossy dielectric materials. When an electromagnetic field impinges on the laptop cover, some part of the incident energy is reflected, another part is lost in the form of surface waves, and some other portion is dissipated in the lossy cover. As a result, the electromagnetic energy transmitted through the laptop cover is attenuated. An experimental study of the antenna peak gain attenuation in a normal incidence configuration is performed (Fig. 1). Laptop covers used in the experiments in this section are named *material A* and *material B*. Both material covers are 2 mm thick and have been characterized at 60 GHz. The dielectric properties are: $\varepsilon_{ra} = 3.1, \tan\delta_a = 0.01$ and $\varepsilon_{rb} = 3.45, \tan\delta_b = 0.025$ for *material A* and *material B*, respectively.

Fig. 2 shows the variation of the antenna peak gain with frequency when *material A* and *material B* are positioned at the

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A. L. Amadjikpè, B. Pan, Y. Li, and J. Papapolymerou are with the School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332 USA (e-mail: arnaud.amadjikpe@gatech.edu).

D. Choudhury is with Intel Corporation, Hillsboro, OR 97124 USA.

G. E. Ponchak is with the NASA Glenn Research Center, Cleveland, OH 44135 USA.

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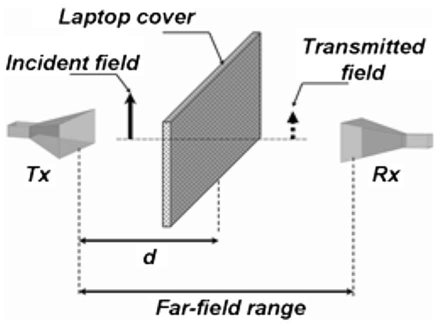

Fig. 1. Test setup for the antenna peak gain attenuation measurement in a normal incidence configuration.

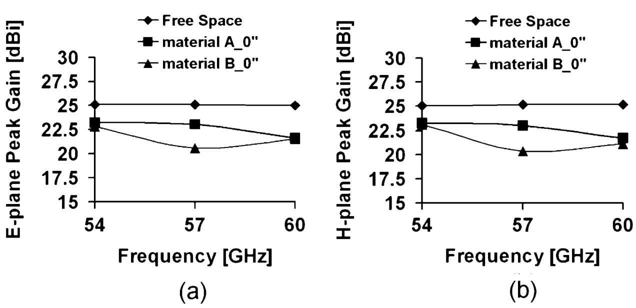

Fig. 2. Peak gain variation as a function of frequency, in free space, with *material A* and *material B* at $\mathrm{d} = 0''$: (a) E-plane, (b) H-plane.

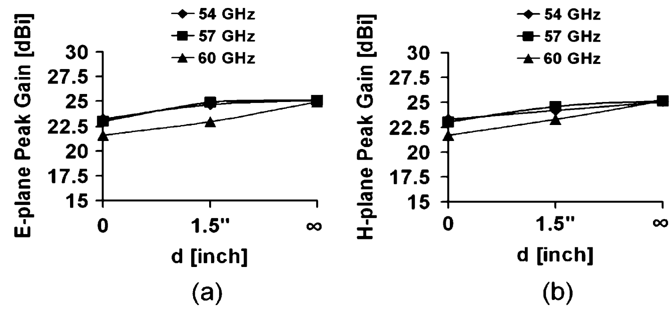

Fig. 3. Peak gain variation as a function of distance d between horn antenna and *material A*: (a) E-plane, (b) H-plane.

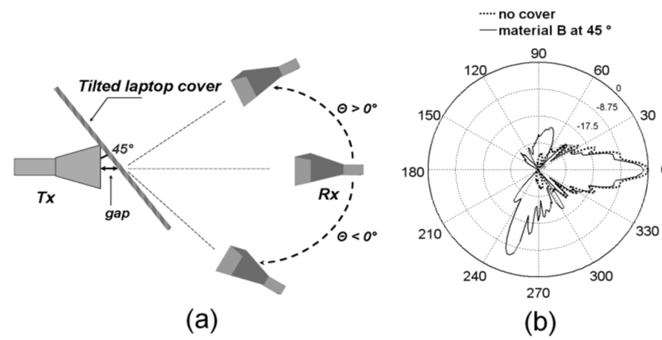

Fig. 4. (a) Test setup for the antenna peak gain attenuation measurement in an oblique incidence configuration. The receiving horn (Rx) is rotated in the E-plane (or Θ-plane). (b) Measured normalized E-plane radiation pattern (at 60 GHz) of the transmitting horn in free space and with *material B* rotated by 45°.

open end of the transmitting horn antenna ($d = 0''$). The case $d = 0''$ represents the worst-case scenario where the cover is in close proximity of the horn aperture. With *material A*, the peak gain decreases with frequency, and at 60 GHz, it is 1.62 dB less than the value at 54 GHz. In the measured band, it is observed that *material A* attenuates the antenna peak gain by 1.9 to 3.38 dB, compared to the free-space values.

With *material B*, a similar behavior is observed, but the overall attenuation with *material B* is higher than that of *material A* by about 1 dB at 54 and 60 GHz. However, there is a significant 2.5-dB gain attenuation difference between the two covers at 57 GHz. The higher attenuation with *material B* can be interpreted from the fact that the loss tangent of *material B* is higher than the loss tangent of *material A*. Furthermore, the higher gain attenuation at 57 GHz may reflect that *material B* exhibits some frequency selectivity at that frequency.

It is important to notice that these peak gain values have been measured in E-plane and then the H-plane. The good agreement between the E-plane and H-plane peak gain values proves the repeatability of those measurements. For both laptop covers, it is seen that the radiation characteristics are not dependent on the field polarization, which shows that these plastic cover materials are isotropic.

This first set of experiments shows that the peak gain attenuation depends on the laptop cover material dielectric properties and also on the operating frequency. Both covers used in these experiments have the same thicknesses. However, it is intuitively known that the attenuation will be higher with the increase in cover material thickness. Therefore, it might be relevant to perform some preliminary material study and benchmark to make a good judgment on the types and thicknesses of covers used for 60-GHz portable devices.

Fig. 3 shows the antenna peak gain variation as a function of the distance d between the transmitting horn antenna and the cover *material A*. The antenna peak gain increases with d and converges to the free-space case $(d = \infty)$ at all frequencies. Scattering of the electromagnetic fields increases as the cover gets closer to the antenna, resulting in greater attenuation. It is also observed that at 60 GHz, the peak gain drops faster than at lower frequencies as the cover approaches the antenna. In practical cases, the plastic cover must be placed as close as possible to the transmitting antenna to maintain a small platform case or an overall small device. Thus, measurements near the $d = 0''$ case are close to real-case scenarios where antennas are laptop-mounted.

B. Oblique Incidence of the Antenna Main Beam to the Plastic Cover

In the previous subsection, 60-GHz antennas radiating perpendicularly to laptop covers have been characterized. However, the antenna main beam may not be directed normally to the cover due to the cover shape of the laptop (or a portable device in general) as well as the antenna placement. Hence, it is important to investigate a case where the cover is not perpendicular but inclined to the transmitting antenna.

Fig. 4(a) shows a laptop cover (*material B*) tilted by approximately 45° in the horn antenna E-plane. By tilting the cover, a small gap of about $2''$ is created between the horn and the cover, in the direction of the main beam.

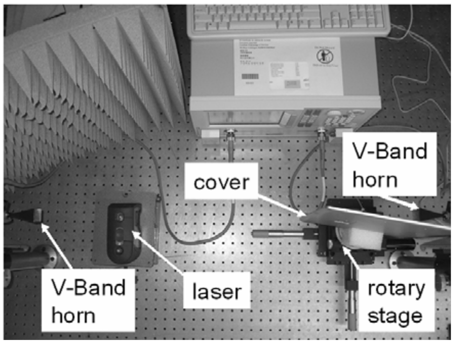

Fig. 5. Experimental setup to characterize diffraction from laptop cover. For the photograph, the microwave absorber is removed. The laser is aligned between two V-band horns.

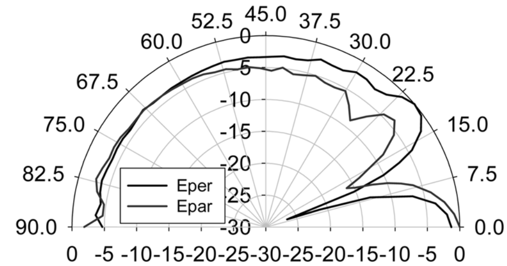

Fig. 6. Measured normalized propagation between two antennas as a function of angle of laptop cover between the antennas. E_{per} and E_{par} are the electric field respectively polarized perpendicular and parallel to the cover at its initial position 0°.

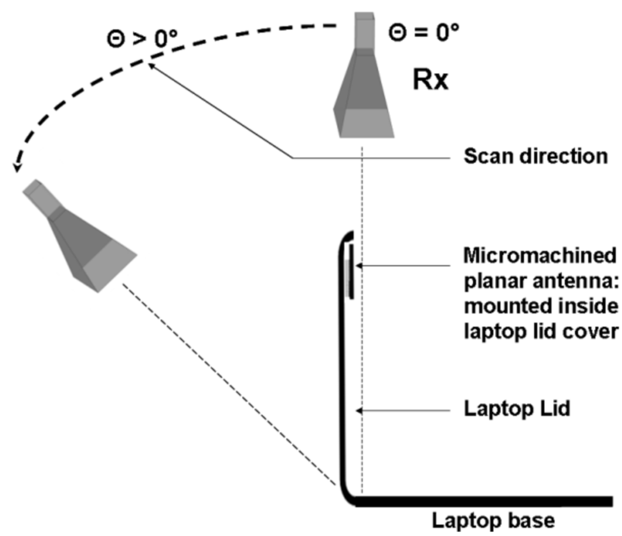

Fig. 7. Setup used to characterize edge diffraction effects onto the micromachined V-band planar antenna.

As shown in Fig. 4(b), tilting the cover in the antenna E-plane creates a reflected image that appears also in the E-plane (the reflected image would appear in the H-plane if the laptop cover was tilted in the H-plane). In this case, the reflected image is directed toward $\Theta = 250°$, and its peak gain level is measured to be 19.26 dBi at 60 GHz. It is important to notice that the reflected image is only 4.32 dB lower than the main beam. Any user that is aligned with the reflected image could, thus, catch this reflected signal, a situation that should be avoided in secure high-speed wireless communications.

At the same time, it is seen that the main beam gain drops by about 1.41 dB with respect to the free space. The $2''$ gap explains why the main beam attenuation is only about 1.41 dB.

The results are very useful to predict the signal attenuation in real-case scenarios where printed planar antennas, on-chip antennas, or other types of laptop-mounted antennas are used.

III. Diffraction Effects Due to Plastic Laptop Cover

In Section II, the transmitting antenna was placed in the proximity of laptop covers such that the main beam impinges toward the center of the cover surface. However, it may happen that the antenna main beam is directed toward the cover edges, depending on the antenna placement on the laptop cover. As the thickness (∼2 mm) of the cover edges approaches the half-wavelength at 60 GHz, diffraction of the incident fields may occur from those edges, and this section focuses on the characterization of this effect.

Fig. 5 shows the experimental setup to investigate the propagation characteristics (at 60 GHz) as a function of the angle of incidence to the laptop cover, *material B*. The cover is placed on a rotary stage that may be moved with an *xy*-axis positioner. For the measurements, two V-band horns (MA/COM 3-15-725) remained fixed and aligned, and the cover is rotated. A laser is positioned between the two V-band horns to determine the place on the cover that corresponds to the measured angle; for the data shown here, the front edge of the cover aligns with the two horn antennas at 10°. Fig. 6 shows the measured results for the horn antennas aligned with the electric field perpendicular and parallel to the cover when this one is in its initial position 0°. It is seen that a null in the radiation magnitude occurs at 10° when the edge of the cover is directly between the antennas. It is also seen that there can be an increase in magnitude because of constructive interference from the cover.

Consequences of diffraction at the cover edges have been experimentally identified. The results could have been derived using diffraction theory [8], but the purpose of this work was to make observations for practical uses. The two standard horn antennas were used to accurately determine the null locations in the antenna radiation pattern.

IV. Micromachined Planar Antenna in Proximity of a Plastic Laptop Cover

This experiment emulates a scenario where a micromachined V-band planar antenna is mounted on the laptop lid, *material B*, so as to radiate toward the top edge of the cover (Fig. 7). In practice, this may simply represent the case where a link is established between a user (laptop-mounted planar antenna) and a wireless access point (Rx) located on a roof. This experiment is meant to identify, at 60 GHz, diffraction nulls when the antenna is mounted close to cover edges and its main beam points toward the cover edge.

As mentioned in [6], the micromachined planar antenna has an E-plane pattern tilted to the upper space because of the 6-mm metal strip (Fig. 8). Hence, the measured peak gain points in the $\Theta = 30°$ direction and equals 14.6 dBi (see Fig. 9 for the plot (dotted line) of the E-plane pattern in free space—$\Theta = 0°$

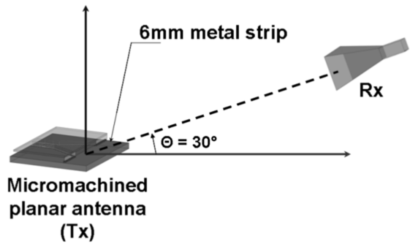

Fig. 8. Measurement setup of the micromachined V-band planar antenna in free space: $\Theta = 30°$ angle shows the peak gain direction of this antenna in the E-plane.

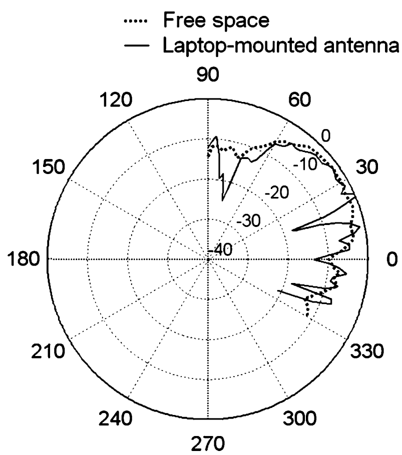

Fig. 9. Measured normalized radiation pattern at 60 GHz of the micromachined planar antenna: in free space (dotted line) and with antenna mounted in the lid (solid line).

is aligned with the antenna axis). The pattern is shown only between $-30°$ and $+90°$ because of the mechanical limitations of the measurement setup.

Fig. 9 shows the radiation pattern of the micromachined planar antenna. A deep null (-2.3 dBi) appears in the $\Theta = 19°$ direction. This null is caused by destructive interference of the fields diffracted from the top cover edge, which is intersecting with a portion of the antenna beam. The transmitting antenna peak gain now points toward the $\Theta = 24°$, and equals 15.6 dBi. This is 1 dB higher than the free-space peak gain and is considered to be a consequence of constructive reflections generated from the cover.

Nulls in the radiation pattern that are as low as -2.3 dBi may result in severe link failures in the direction of the null formation. In the case where a very high data rate point-to-point link is to be established, 60-GHz antenna beamwidth requirements may be under $1°$ [1], in which case a single null in the radiation pattern can be very drastic. However, if the targeted application does not require very narrow beamwidths, a single null in the pattern might be acceptable. Nevertheless, some covers may have a structure that creates several nulls, in which case even a wide-beam application becomes affected.

V. Discussion and Conclusion

This letter raised very important aspects concerning the development of 60-GHz antennas in the proximity of real plastic cover materials. It was found that the properties of the cover materials strongly affect the performance of the antenna. Two commercial laptop cover materials were used in this work to show the typical behavior that may be expected each time a 60-GHz antenna is mounted or used in the proximity of a laptop platform.

However, the observed results may change as the properties or the overall structure of the cover materials change. Some covers may have metallization at some locations, which obviously prevents the antenna from being located right at those locations. Some covers may not have consistent thicknesses at all regions of the cover, which will result in different attenuation as the antenna location is changed. Other covers with geometrical irregularities at the edges, such as the plastic joints used to close the laptop lid, might increase diffraction and create several nulls in the antenna radiation pattern. Antenna location inside the laptop platform should then be evaluated case by case to determine the best-case scenarios in terms of RF performance. Sometimes, because of mechanical and packaging constraints, some locations are prohibited, in which case the RF performance may need to be somewhat sacrificed or compensated with the use of beam-steerable antennas and/or power amplifiers to boost antenna gain throughout the cover material.

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